CHAPTER 4

Threats to Salmonids

Chapter 4 identifies and prioritizes threats to ESUs in the Columbia River basin. Threats are the human actions or natural events, such volcanic eruptions or floodplain development, that cause or contribute to limiting factors (Gaar 2005). Threats may be caused by past, present, or future actions or events.

The threats presented in this chapter were identified and prioritized using the same process and sources used to identify and prioritize limiting factors—that is, a thorough review and synthesis of pertinent literature (particularly Bottom et al. 2005, Fresh et al. 2005, and Northwest Power and Conservation Council 2004), supplemented by input by area experts. Both limiting factors and threats are well documented in these three key source documents, as well as in a number of other primary sources. In most cases limiting factors and threats are addressed together in the literature, and it required substantial effort to separate them for the purposes of this estuary recovery plan module.

The one threat presented in this chapter that was not mentioned in the main source documents is ship wakes, which can cause stranding of juvenile salmonids. Although the topic of stranding was first raised in a 1977 report (Bauersfeld 1977), the extent of stranding is unclear and the issue has remained quietly controversial and unresolved. The topic is addressed in this recovery plan module at the request of the Washington Department of Fish & Wildlife because ship wakes are speculated to cause significant levels of mortality to ocean-type juveniles (primarily fry).

This chapter organizes threats to salmonids into the following groupings: flow, sediment, structures such as dikes and jetties, ship wakes, food web (including species relationships), and water quality in the estuary. The presentation of threats as discrete activities or phenomena is an oversimplification of complex physical and biological relationships that affect salmon survival. The threats related to flow, sediment transport, and food webs are particularly difficult to tease apart and discuss discretely. Thus the reader should bear in mind that describing threats individually does not fully capture the dynamic interplay of forces that are currently putting salmonids in the estuary at risk. The complexity of these forces is illustrated in Figure 4-1, which is a representation of a conceptual model of the Columbia River estuary developed by the U.S. Army Corps of Engineers. The model provides in-depth detail on the relationships between limiting factors and threats.

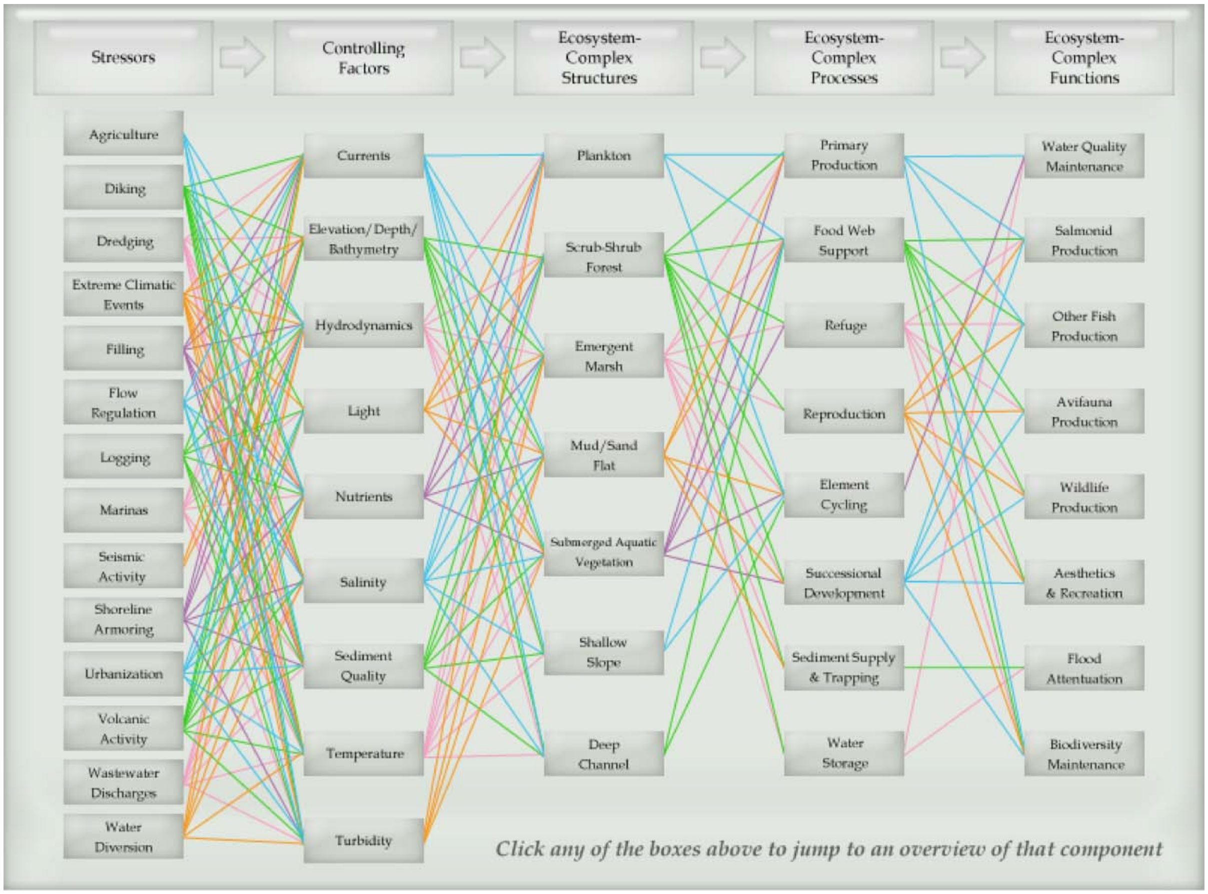

FIGURE 4-1
U.S. Army Corps of Engineers Conceptual Model of the Columbia River Estuary
(Note: "Stressors" are equivalent to threats as defined in this module.)

Most of the human threats described in this chapter are the result of the cumulative impacts of people living in the Northwest. From an ecological perspective these impacts have taken place relatively quickly. Consider that in 1770, when American Robert Gray first crossed the Columbia River bar, about 100,000 Native Americans lived in the Columbia River basin (Oregon State University 1998). Today the population of the Columbia Basin is approximately 5 million (National Research Council 2004). In the early years of Euro-American settlement, the area's abundant natural resources supported farming, mining, logging, fishing, and other activities that modified the landscape into productive uses for people. Later, the availability of cheap hydroelectric power helped fuel expanded agriculture, manufacturing, and development and the rise of urban centers such as Portland. The impacts of these activities on salmonids in the estuary have been substantial.

Flow-Related Threats

Over the last 4,000 years, salmon thrived in the Columbia River by adapting to habitats created by characteristics of the land and water flow (Fresh et al. 2005). Key attributes of flow include magnitude and timing, both of which have changed significantly in the Columbia River over the last two centuries. Today the mean flow to the estuary is about 16 percent less than it was in the latter part of the nineteenth century (Jay and Kukulka 2002), and spring freshet peak flows have declined about 44 percent in that same time period (Jay and Kukulka 2002). In addition, the timing of peak flows occurs about 14 to 30 days earlier than it did historically (Jay and Kukulka 2002). Reductions in the spring freshet flows are shown in Figure 4-2, which presents simulated mean monthly discharge at Bonneville Dam before development of the hydrosystem and under current hydrosystem configurations and operations.

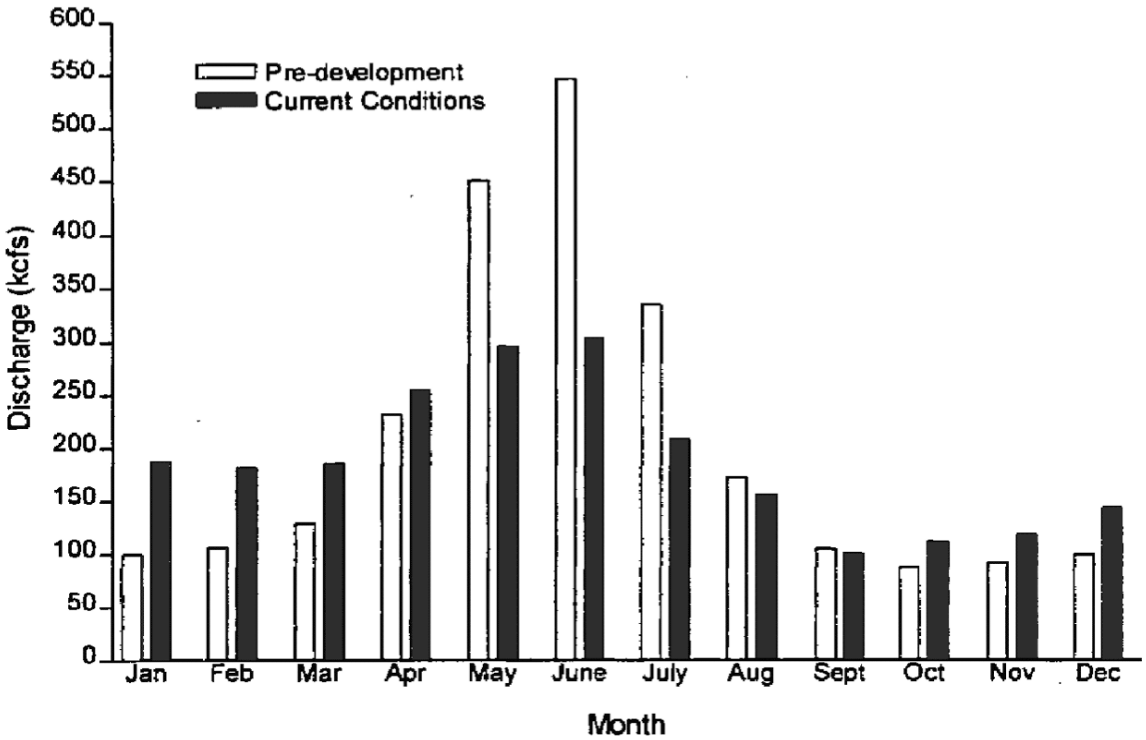

FIGURE 4-2
Changes in the Annual Columbia River Flow
(Adapted from National Marine Fisheries Service 2000.)

Flow alterations, in connection with other factors, can increase or decrease salmonids' ability to access habitats and the capacity of habitats to sustain salmonids (Bottom et al. 2005). In the case of the Columbia River, alterations in the timing, magnitude, and duration of flows are responsible for dramatic changes in habitat opportunity and capacity in the estuary. Climate fluctuations, the withdrawal of water, and regulation of river flow have altered the amount and timing of instream flows entering the estuary and plume.

Affected salmonids: Alterations in the magnitude and timing of Columbia River flows affect both ocean- and stream-type juvenile salmonids. Ocean-type juveniles spend more time in the estuary, where they rely on shallow vegetated marsh habitats and upland swamp habitats (Northwest Power and Conservation Council 2004). Chum salmon (ocean-type) also spawn in the mainstem and are affected by low flows during the spawning and egg incubation life stages—in extreme cases, redds may be dewatered. Ocean-type salmonids also rely on seasonal overbank flows to access habitats and preferred food sources.

Stream-type juveniles do not spend much time in the estuary, but recent research indicates that they may use the Columbia River plume habitat as they adjust to saltwater conditions

(Fresh et al. 2005). Columbia River flows have a direct effect on the plume's surface area, volume, frontal features, and extent offshore (Fresh et al. 2005). Flow alterations also affect sediment transport processes.

Threat: Climate Cycles and Global Warming

Natural variations in Columbia River flow as a result of long- and short-term climate fluctuations have occurred throughout history. The Pacific Decadel Oscillation (PDO) alternates between cold and warm phases approximately every 30 years (Fresh et al. 2005). The cold, rainy phase is typical of the Northwest and increases flows, while the warm phase is drier and decreases flows (Fresh et al. 2005). The El Niño/Southern Oscillation (ENSO) is a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that may magnify or reduce the effects of the PDO.

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Over the last 100 years, climatic changes have reduced Columbia River flows by 9 percent (Jay and Kukulka 2002). NOAA/NMFS's Northwest Fisheries Science Center has observed changes in PDO and ENSO indicators that suggest that changes in ecosystem structure can be expected that are unfavorable for salmon and steelhead (Varanasi 2005). These changes may continue over the next several years.

Scientists believe that the release of high levels of carbon dioxide as a result of human activities is responsible for global warming. The source of these releases includes the use of fossil fuels to run cars, heat homes and offices, and power factories. Over the past century, global warming has caused sea levels to rise about 4 to 5 inches, worldwide precipitation to increase by about 1 percent, and the frequency of extreme rainfall events to increase in much of the United States (U.S. Environmental Protection Agency 2005). Sea level rise is predicted to accelerate worldwide in the coming decades as a result of global warming (Intergovernmental Panel on Climate Change 2001 as cited in Williams et al. 2004). For average modeling parameters, the Intergovernmental Panel on Climate Change projects that, during the next 50 years, sea levels will rise between approximately 2 and 4 millimeters per year, depending on the emissions scenario. This is roughly twice the rate during the 20th century (Intergovernmental Panel on Climate Change 2001 as cited in Williams et al. 2004). Within the Columbia River basin, other expected effects of rising temperatures include more precipitation falling as rain rather than snow, diminished snow pack and associated reductions in spring and summer flow, increased peak river flows, and continued rises in water temperatures. In the estuary, these factors could lead to changes in flooding, sediment transport, food web dynamics, populations of non-native species, and water temperature (Independent Scientific Advisory Board 2007). Other impacts in the estuary may include continued rises in sea level and associated effects on intertidal habitat formation and maintenance. Additional research will be needed to understand the likely effects of global warming on estuarine habitats and processes with any specificity.

While global warming is a growing concern, this estuary recovery plan module does not consider it separately from other climate-related impacts in the estuary. However, global warming should receive increasing attention for its potential to affect fish management in the Columbia River basin as a whole.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Threat: Water Withdrawal

Reduction in the amount of instream flow in a river system is an important measure of alterations to the system (Fresh et al. 2005). Water withdrawals affect both the magnitude and timing of flows entering the estuary and plume.

Historically, flow conditions in the estuary were determined by seasonal climate effects (such as precipitation) and hydrology. Since the early 1900s and to a larger degree since the 1960s, irrigation practices have reduced flows in the Columbia River. Water withdrawals as a result of agricultural irrigation and other water uses are estimated to have reduced flows of the Columbia River by 7 percent since the latter part of the nineteenth century (Jay and Kukulka 2002).

Other human activities that reduce flows are the result of upstream use of surface water and groundwater for commercial, industrial, municipal, domestic, and other purposes (National Research Council 2004).

Irrigation withdrawals of surface water account for approximately 96 percent of total water used, while municipal and other uses account for only 4 percent (National Research Council 2004). On the other hand, about 75 percent of all groundwater withdrawals support irrigation and the remaining 25 percent are used for other purposes (National Research Council 2004).

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Threat: Flow Regulation

The timing and magnitude of spring freshets have been drastically altered by management of the Columbia River hydrosystem (Fresh et al. 2005). Jay and Kukulka (2002) estimate that 26 percent of the overall reduction of freshet season flow since the late nineteenth century is attributable to flow regulation. Together with irrigation, flow regulation has increased fall and winter flows (winter flows have increased because of pre-release before the freshet season), and much of the seasonal timing of flows in the estuary can be attributed to flood control and hydroelectric operations.

Flow regulation is a function of the hydrosystem in the United States and Canada. The first hydroelectric facility in the lower Columbia Basin—the T.W. Sullivan Dam in Oregon City—was constructed in 1888. Since then, more than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). These dams supply British Columbia with 50 percent of its electricity, while the American Northwest relies on hydropower for about two-thirds of its electricity (Columbia Basin Trust). Columbia River dams also provide flood control, enhance irrigation, and improve navigation.

The total active storage of water in the Columbia River Basin is 42 million acre-feet (Northwest Power and Conservation Council 2001), with dams in Canada accounting for about half of the total storage (Northwest Power and Conservation Council 2001). Major Canadian dams include the Duncan, Arrow, and Mica dams. Major U.S. hydroelectric facilities with significant storage include the Grand Coulee, Dworshak, Hungry Horse, and Libby dams. In addition, the U.S. Bureau of Reclamation owns and operates dozens of water storage dams in the Snake and Yakima rivers. The U.S. Army Corps of Engineers also operates many large flood control projects in the Willamette River.

Several recent changes in hydrosystem operations have been implemented to benefit salmonids throughout the basin. These include increasing flows by minimizing winter flood control drafts and reducing the amount of water needed to refill projects during the spring—measures that benefit spring juvenile salmonid migration in the mainstem Snake and Columbia rivers. Also, summer flows have been augmented to cool Snake River temperatures and assist Snake River fall chinook migration. Finally, a minimum flow has been administratively set from November through April to reduce the potential for dewatering of chum redds, primarily in Reach G in the estuary.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Sediment-Related Threats

Changes to seasonal flows, dredging, and the entrapment of sediment in reservoirs have altered those habitat-forming processes in the Columbia River estuary, plume, and nearshore that relate to sediment.

As described in Chapter 3, the transport of sediment is fundamental to habitat-forming processes in the estuary. Sediment helps create and maintain and promote wetlands, which are important to carbon cycling in the estuary and provide habitat for juvenile salmonids. Sediment also provides important nutrients that support food production in the estuary and plume. And suspended sediments contribute to turbidity, which is an important to salmonids because of the protection it provides from predators Although the effects of impaired sediment processes on salmonids in the estuary are not fully understood, the magnitude of change and the key role that sediments play in habitat- and food-related processes are significant.

Entrapment of sediment in reservoirs, reduced downstream transport of sediment as a result of altered spring freshets, and dredging are the primary sediment-related threats to salmonids in the estuary. Ocean-type juvenile salmonids are affected by sediment-related changes in habitat in the estuary. Stream-type juveniles are affected by reduced turbidity (which can increase predation) in deeper waters in the estuary and plume.

Threat: Entrapment of Fine Sediment in Reservoirs

Reduction in water velocity as a result of upstream reservoirs has altered the transport of organics associated with fine sediments such as silt and clay. Fine sediments entering the estuary originate in the upper watersheds of the Snake River (Northwest Power and Conservation Council 2004). Reduced velocities behind upstream reservoirs act as a sink to fine sediments and likely reduce amounts delivered to the estuary (Northwest Power and Conservation Council 2004). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Flow-related plume changes, sediment/nutrient-related estuary habitat changes, native birds, native fish, and exotic fish.

Threat: Impaired Transport of Coarse Sediment

Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly ocean types. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2002). It is likely that the magnitude of change in sand transport affects habitat-forming processes and reduces turbidity, which results in increased predation in the estuary and plume environments.

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Dredging

Dredging and the disposal of sand have been a major cause of estuarine habitat loss over the last century (Northwest Power and Conservation Council 2004). Currently, three times more sand is dredged from the estuary than is replenished by upstream sources (Northwest Power and Conservation Council 2004). In addition to causing habitat loss, dredging may have impaired sediment circulation systems in nearshore ocean areas.

Additional losses of vegetated wetlands in the Columbia River estuary are attributable to filling activities, with deposition of dredged materials accounting for most of the filling activities in the estuary (Fresh et al. 2005). Most dredged materials result from maintenance of the shipping channel. Dredged materials are disposed of in-water, along shorelines, or on upland sites; some dredged material disposal sites are shown in the reach maps in Appendix A. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year (Northwest Power and Conservation Council 2004). Dredge fill activities have significantly reduced the availability of wetlands to the river.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and native birds.

Structural Threats

The development of instream and over-water structures has altered circulation patterns, sediment deposition, sediment erosion, and the formation of habitats in the estuary. Examples of instream and over-water structures include jetties, pile dikes, tide gates, docks, breakwaters, bulkheads, revetments, seawalls, groins, and ramps (Williams and Thom 2001). Such structure create favorable conditions for predators such as northern pikeminnow and walleye, and they can reduce circulation in areas outside of the channel. Instream and over-water structures are found in all reaches of the estuary (for locations, see the reach maps presented in Appendix A).

Another structural threat is reservoirs associated with the hundreds of dams in the Columbia River basin. The construction and operation of these reservoirs has contributed to changes in the temperature of water entering the estuary.

Affected salmonids: Structural threats primarily affect ocean-type juvenile salmonids because of their longer residency time in the estuary and their wider use of off-channel habitats; however, scientists are now hypothesizing that stream-type juveniles forage outside of deeper channels in shallow-water habitats, where they may fall victim to predators that congregate near instream and over-water structures.

Threat: Pilings and Pile Dike Structures

Construction of the North and South jetties has altered sediment accretion and erosion processes near the mouth of the Columbia River. Sediment accretion in the marine littoral areas adjacent to the mouth has decreased the inflow of marine sediments into the estuary (Northwest Power and Conservation Council 2004), while the extensive use of pilings, pile dikes, and other structures to maintain the shipping channel has affected natural flow patterns. Development of the navigation channel has reduced flow to side channels and peripheral bays (Northwest Power and Conservation Council 2004). Docks, piers, and other structures have altered habitats and created favorable conditions for predators, especially the northern pikeminnow and non-native species such as small-mouth bass. In addition, saltwater intrusion patterns have been altered and nutrient cycles have been interrupted.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and exotic fish.

Threat: Dikes and Filling

Dikes and filling activities have significantly altered the size and function of the Columbia River estuary. Since the early 1900s, dikes have been built to allow agricultural and residential uses (Fresh et al. 2005). Dikes are thought to have caused more habitat conversion in the estuary than any other human or natural factor (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). The effects of diking on estuarine habitats are directly proportional to elevation, with the greatest impacts on the highest elevation estuarine habitats: forested wetlands, followed by tidal swamps and tidal wetlands. Diking-related impacts to these habitats have reduced their availability to juvenile salmon and steelhead (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). Figure 4-3 shows the various zones found in typical estuaries. The emergent vegetation, diked marsh, shrub wetlands, and forested wetlands are the zones most affected by dike and filling practices (reprinted from Thom 2001). Diked areas and the historical floodplain in the Columbia River estuary are shown in the reach maps presented in Appendix A.

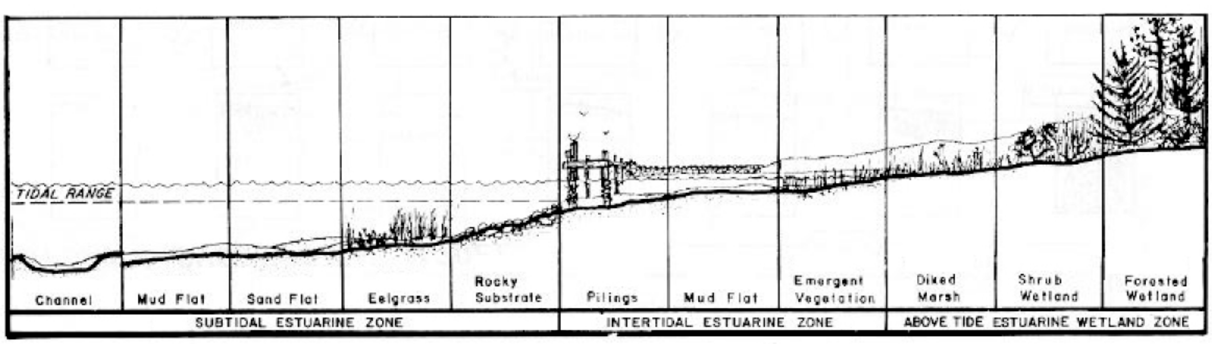

FIGURE 4-3
Subtidal, Intertidal, and Above-Tidal Estuarine Wetland Zones

Before development of the Columbia River hydrosystem and diking and filling, the estuary was dominated by macrodetrital inputs that originated from vegetated wetlands within the estuary. As a result of diking and filling practices and flow alterations (such as changes in the number and timing of spring freshets), emergent plant production in the estuary has decreased by 82 percent and macroalgae production has decreased by 15 percent (Northwest Power and Conservation Council 2004). The availability of insect prey for ocean-type salmonids has been reduced as vegetation has been removed via diking and filling activities and associated dike vegetation maintenance.

Limiting factors this threat contributes to: Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat and plume changes, bankfull elevation increases, and exotic plants.

Threat: Reservoir-Related Temperature Changes

More than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). The associated impoundment of water in upstream reservoirs increases the surface area of the Columbia River, allowing more solar heating of river water than occurs in free-flowing river stretches. This solar heating, combined with the reduced flows from upstream impoundments, has contributed to increased water temperatures in the Columbia River. Measurements at Bonneville Dam indicate that periods of increased temperatures are lasting longer than they did historically (National Research Council 2004). Currently, average and maximum values of Columbia River water temperatures are well above 20° C, which approaches the upper limits of thermal tolerance for cold-water fishes such as salmon (National Research Council 2004).

The dynamics of reservoir-related temperature changes in the estuary are complicated and are affected by factors such as thermal inertia, which, among other things, contributes to delayed fall cooling and spring warming of downstream waters. Additional study is needed to better understand reservoir-related temperature changes and their effects on salmonids rearing in the estuary.

Limiting factors this threat contributes to: Water temperature.

Threat: Over-Water Structures

Over-water structures refer to docks, transient moorage, log rafts, and other structures. These structures block sunlight, reduce flow, and trap sediments downstream of pilings. Over-water structures create microhabitats that may enhance predator habitats, alter circulation patterns, and reduce edge habitats for ocean-type salmonids. Although the actual square footage of over-water structures in the Columbia River estuary has never been inventoried, the structures themselves number in the thousands. Some research has occurred on the effects of breakwaters and over-water structures in the context of marinas. Salmon fry tend to concentrate in higher densities around these structures, thus increasing the risk of predation (Williams and Thom 2001).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, and exotic fish.

Food Web-Related Threats

As described in Chapter 3, changes in the estuarine food web can ripple through the ecosystem, altering feeding patterns, predator/prey relationships, and competition within and among species. The introduction of exotic species such as shad may have accelerated the pace of ecological change in the estuary by permanently altering food webs. Food webs also have been altered by sediment transport, in that microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically.

Affected salmonids: Both stream- and ocean-type salmonids are affected by energy-related threats—stream types primarily through increased predation in deep-water habitats and ocean types primarily through food web changes in the estuary. Ocean-type juveniles also are affected by reduced availability of insect prey as a result of the construction and maintenance of dikes.

Threat: Reservoir Phytoplankton Production

A reduction in macrodetrital inputs has shifted the plant primary production in the estuary to phytoplankton produced in and imported from upstream reservoirs (Northwest Power and Conservation Council 2004). Imported phytoplankton support a pelagic food web that is less accessible to ocean-type salmonids occupying shallow edge habitats (Northwest Power and Conservation Council 2004). The shift in primary plant production from a macrodetrital base to a microdetrital base has provided different food sources than historically existed, in different places within the estuary, that may favor different species. Because this area of study is immature in the estuary, it is difficult to establish which species benefit more than others.

Limiting factors this threat contributes to: Increased microdetrital inputs.

Threat: Altered Predator/Prey Relationships

Although predation has always occurred in the estuary ecosystem, the cumulative effect of altered flows, changes in sediment transport processes and food sources, introduced species, hatcheries, upstream habitat impacts, hydroelectric impacts, and contaminants have recast estuary and plume environments such that predator/prey relationships have changed significantly. As a result, significant numbers of salmon are lost to fish, avian, and marine mammal predators during migration and residency in the estuary (Northwest Power and Conservation Council 2004). Fish predators include northern pikeminnow, walleye, smallmouth bass, and catfish; avian predators include Caspian terns, double-crested cormorants, and gull species; and marine mammal predators include Steller and California sea lions and harbor seals.

Degraded conditions (loss of habitat and reduced food web productivity) in the Columbia River estuary and the timing of large hatchery releases have increased the likelihood that mortality from competition may occur under some circumstances (Northwest Power and Conservation Council 2004). Mortality from inter-species competition has been documented in the Skagit River estuary (Beamer et al. 2005), and there is speculation that it may be a factor in the Columbia River as well (Northwest Power and Conservation Council 2004). If inter-species competition is occurring, it is likely to have the greatest impact on ocean-type salmonids because of their longer residence time in the estuary (Northwest Power and Conservation Council 2004). If density dependence is affecting stream-type juveniles, it likely happens in the plume.

As the result of human alterations of the estuary environment, native species such as Caspian terns and double-crested cormorants have significantly increased in number, with measurable impacts on stream-type salmonids (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). These increases in population in the Columbia River estuary are attributed to the deposition of dredged materials in the estuary that represent high-quality habitat for the birds (Bottom et al. 2005) and predation opportunities for cormorants created through the placement of pilings, pile dikes, and other structures. The loss of habitat elsewhere has contributed to terns and cormorants effectively relocating to the Columbia River estuary, with the populations there now representing the largest nesting colonies in the world. Similarly, the new microdetritus-based food web in the estuary has benefited zooplanktivores, including American shad (an introduced species) (Northwest Power and Conservation Council 2004). Although shad do not appear to be in direct competition with salmonids, their biomass alone—more than 4 million returning adults a year—represents a threat to trophic relationships in the Columbia River. Other exotic fish species such as introduced walleye and catfish also have been able to capitalize on degraded conditions in the upper reaches of the estuary and alter food web dynamics through predation and competition for food resources. Walleye, for example, prey directly on juvenile salmonids.

Pinniped predation on adult spring chinook and winter steelhead continues to increase. On the West Coast the total abundance of California sea lions is approximately 250,000, Stellar sea lions total about 31,000, and Pacific harbor seals total about 25,000 (Griffin 2006). Each spring about 1,000 Stellar sea lion males, 3,000 Pacific harbor seals, and 800 California sea lions take up residence in the lower estuary (Griffin 2006). A small fraction of the 1,000 sea lions entering the freshwater (approximately 80) congregate at Bonneville Dam and have been estimated to cause mortality of up to 3.6 percent of all spring chinook and winter steelhead (U.S. Army Corps of Engineers 2005). There are no estimates of the mortality caused by the remaining pinnipeds in the saltwater portion of the estuary and plume or the 200 to 250 Stellar sea lions between Longview and Beacon Rock. Unsubstantiated estimates may exceed 10 percent of the entire adult spring chinook and steelhead runs in a given year.

Non-native plant species have altered habitat and food webs in the Columbia River estuary. The rate of intentional and unintentional introductions has been increasing over the past 100 years, mostly as a result of horticultural practices and the increase in travel and commerce in the Columbia River. Four of those species—purple loosestrife, Eurasian water milfoil, parrot feather, and Brazilian elodea—are of particular concern. Each of these species, in its own way, alters habitat and food webs in the estuary. Purple loosestrife, for example, adapts easily to environmental changes and expands its ranges quickly. The primary ecological effect of purple loosestrife is that it disrupts wetland ecosystems by displacing native plants. Eventually, animals that rely on native flora for food, nesting, or cover also are displaced (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Native birds, native fish, native pinnipeds, introduced invertebrates, exotic fish, and exotic plants.

Threat: Ship Ballast Practices

Ship ballast practices have been responsible for the introduction of at least 21 exotic species in the Columbia River estuary (Sytsma et al. 2004). When ships release ballast water, non-indigenous species can enter receiving waters. Most of the non-indigenous species in the estuary have originated from Asia (Sytsma et al. 2004). Populations of non-native copepods have established themselves in Reaches A and B (Youngs Bay, Cathlamet Bay, and Grays Bay), and the New Zealand mudsnail has colonized other estuary reaches. The Asian bivalve *Corbicula fluminea* has expanded its range in the estuary, with densities of 10,000 per m^2 being recorded in Cathlamet Bay; however, densities of 100 to 3,000 m^2 are more common (Northwest Power and Conservation Council 2004). These and other non-indigenous invaders disrupt food webs and out-compete juvenile salmonids' native food sources.

Limiting factors this threat contributes to: Introduced invertebrates.

Water Quality-Related Threats

The release of toxic contaminants, nutrient loading, and reduced dissolved oxygen have altered the quality of salmonid habitats in the Columbia River estuary. Currently the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from urban and agricultural areas (Fuhrer et al. 1996 as referenced in Fresh et al. 2005). Agricultural, urban, industrial, and timber harvesting practices also affect water quality in the estuary. The literature provides more information about threats related to toxic contaminants than it does about other water-quality issues in the estuary.

Threat: Agricultural Practices

The health of the aquatic ecosystem is substantially affected by agricultural practices and wastewater discharge (National Research Council 2004). Specific threats include increased nutrients (nitrogen and phosphorus), sediment, and organic and trace metals (National Research Council 2004). Agricultural practices in the estuary and throughout the Columbia River basin contribute water-soluble contaminants and other potentially toxic contaminants. The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) program reports that a wide range of commonly used pesticides have been detected at sampling sites near Bonneville Dam and at the confluence of the Willamette and Columbia rivers (Fresh et al. 2005). Detected water-soluble contaminants include simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl. Arsenic and trace metals such as iron and manganese also have been detected. Although trace metals occur naturally, they also are introduced through human activities, such as the use of lead arsenate as an insecticide for apples (Fresh et al. 2005). Water-soluble contaminants, trace metals, and chlorinated compounds have been detected in the estuary (Fresh et al. 2005), and DDT, PCBs, dioxins, and metals have been detected at elevated levels in tissue from fish in the estuary (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Short-term toxicity and bioaccumulation toxicity.

Threat: Urban and Industrial Practices

The Columbia River downstream of Bonneville Dam is the most urbanized stretch in the entire basin. The largest sources of effluent in this area are the Portland and Vancouver sewage treatment plants (Fresh et al. 2005). Contaminants also are transported downstream to the estuary from areas above Bonneville Dam. An intensive study of sediments in Portland Harbor (the stretch of the Willamette River from Sauvie Island to Swan Island) has uncovered pesticides, PCBs, and other toxic chemicals. In general, studies have shown that PCB and PAH concentrations in salmon and their prey in the estuary are comparable to those in organisms in other moderately to highly urbanized areas (Fresh et al. 2005). Industrial contaminants such as PAHs have been detected in sediments from the lower Willamette River in Portland at levels that exceed state or federal sediment quality guidelines. The U.S. Environmental Protection Agency recently identified PCB and DDT hot spots within the estuary, including near Longview, West Sand Island, the Astoria Bridge, and Vancouver (Fresh et al. 2005).

Limiting factors this threat contributes to: Short-term toxicity and bioaccumulation toxicity.

Other Threats

Threat: Riparian Practices

Riparian practices along the estuary mainstem and in tributaries throughout the Columbia River basin have contributed to increases in water temperature in the estuary by changing hydrology and removing riparian habitats (National Research Council 2004), which—among other ecological functions—provide insects and macrodetrital inputs to the food web. Problematic practices include shoreline modifications, timber harvest, certain agricultural activities within riparian zones, and residential, commercial, and industrial land uses. These activities increase water temperatures, alter hydrology and macrodetrital inputs, and in some cases modify shoreline habitats used by salmonids, especially ocean types (Lower Columbia Fish Recovery Board 2004).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, reduced macrodetrital inputs, water temperature, and exotic plants.

Threat: Ship Wakes

Ships traveling through the Columbia River estuary produce waves and an uprush which, under certain circumstances, causes juvenile salmonids and other fish to become stranded on shore (Bauersfeld 1977). Although Bauersfeld concluded that ship wake stranding was a significant cause of mortality in ocean-type chinook salmon and other species, other studies have not confirmed this. As a part of the U.S. Army Corps of Engineers' channel deepening project, a new study is under way that may help characterize the magnitude of ship wake stranding. The purpose of the study is to document ship wake stranding before and after channel deepening. The first half of the study, published in February 2006, documented stranding events at three test sites. The second part of the study will begin after dredging is completed (Pearson et al. 2006). These results should be useful as partial basis for Light Detection and Ranging (LIDAR) analysis and extrapolation of test site mortality throughout the estuary for similar habitat types.

Limiting factors this threat contributes to: Stranding.

Prioritization of Threats

The threats identified above are well supported in a wide variety of literature sources. In many cases, primary literature sources are cross-referenced in the literature and restated and synthesized through comprehensive documents like the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* (Northwest Power and Conservation Council 2004).

The prioritization of threats, though, is not nearly as well supported, partly because of the limited understanding of how threats contribute to limiting factors and to what degree salmon and steelhead are affected by a given limiting factor. While it is attractive to assume that additional study will fully answer these questions, the biological response to environmental conditions will always be difficult to model because of the tremendous complexities of the physical, biological, and ecological interplay that occurs in the environment. On the other hand, new interest in the estuary and its role in the recovery of listed species in the Columbia River has generated better understanding, and it is likely that uncertainty surrounding threats and limiting factors will continue to lessen.

This estuary recovery module establishes priorities for threats by linking them to pertinent limiting factors and estimating their relative contribution to those limiting factors. Literature sources were very useful in making connections between threats and limiting factors. In nearly all cases, authors discussed cause-and-effect relationships in typically qualitative language. In some cases quantitative relationships were established, as in the relationship between flow regulation and sediment transport. Only a handful of sources estimated priorities for either limiting factors or threats.

Table 4-1 links the limiting factors and threats identified in this estuary recovery plan module and estimates the relative contribution of each threat to one or more limiting factors. Although the information presented in the table is oversimplified, given the state of the science the table functions adequately as tool to help identify management actions in Chapter 5.

TABLE 4-1
Linkages Between Limiting Factors and Threats to Ocean- and Stream-Type Salmonids

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
Flow-related estuary habitat changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related changes in access to off-channel habitat	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related plume changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Impaired transport of coarse sediment	Top (5)	Secondary (2)	10
	Entrapment of fine sediment in reservoirs	Top (5)	Tertiary (1)	5
Reduced macrodetrital inputs	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Riparian practices	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Dikes and filling	Top (5)	Primary (3)	15
Water temperature	Reservoir-related temperature changes	Top (5)	Secondary (2)	10
	Riparian practices	Top (5)	Secondary (2)	10

Sediment/nutrient-related estuary habitat changes	Impaired transport of coarse sediment	High (4)	Primary (3)	12
	Entrapment of fine sediment in reservoirs	High (4)	Secondary (2)	8
	Dredging	High (4)	Secondary (2)	8
	Pilings and pile dike structures	High (4)	Primary (3)	12
	Dikes and filling	High (4)	Primary (3)	12
	Over-water structures	High (4)	Tertiary (1)	4
	Riparian practices	High (4)	Tertiary (1)	4
Bankfull elevation changes	Dikes and filling	High (4)	Primary (3)	12
Short-term toxicity	Agricultural practices	High (4)	Primary (3)	12
	Urban and industrial practices	High (4)	Primary (3)	12
Native birds	Entrapment of fine sediment in reservoirs	High (4)	Tertiary (1)	4
	Dredging	High (4)	Secondary (2)	8
	Altered predator/prey relationships	High (4)	Primary (3)	12
Native pinnipeds	Altered predator/prey relationships	High (4)	Primary (3)	12
Bioaccumulation toxicity	Agricultural practices	Medium (3)	Primary (3)	9
	Urban and industrial practices	Medium (3)	Primary (3)	9
Native fish	Entrapment of fine sediment in reservoirs	High (4)	Tertiary (1)	4
	Altered predator/prey relationships	Medium (3)	Primary (3)	9
Increased microdetrital inputs	Reservoir phytoplankton production	Low (2)	Primary (3)	6
Sediment/nutrient-related plume changes	Dredging	Low (2)	Primary (3)	6
	Pilings and pile dike structures	Low (2)	Secondary (2)	4
	Dikes and filling	Low (2)	Secondary (2)	4
Stranding	Ship wakes	Low (2)	Primary (3)	6
Introduced invertebrates	Altered predator/prey relationships	Lowest (1)	Tertiary (1)	1
	Ship ballast practices	Lowest (1)	Primary (3)	3
Exotic fish	Entrapment of fine sediment in reservoirs	High (4)	Tertiary (1)	4
	Over-water structures	Lowest (1)	Secondary (2)	2
	Pilings and pile dike structures	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3
Exotic plants	Dikes and filling	Lowest (1)	Primary (3)	3
	Riparian practices	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3

[a] From Table 3-2.

[b] Indicates how important the threat is in perpetuating the limiting factor:

3 = Threat is a primary cause of the limiting factor. Addressing this threat would significantly improve salmonid performance.

2 = Threat is a secondary cause of the limiting factor. Addressing this threat would improve performance.

1 = Threat is a tertiary cause of the limiting factor. Addressing this threat would benefit performance, but by itself would result in only minor improvement.

[c] Product of the numerical scores for the limiting factor priority and the threat's contribution to the limiting factor. A high threat index score means that the threat is a major contributor to one or more significant limiting factors. A low threat index score means the threat is a small contributor to a minor limiting factor.

To the degree possible, Table 4-1 demonstrates the relationship between threats and limiting factors by showing which threats are causing which limiting factors and estimating the contribution of each threat to the various limiting factors. The contribution scores in the table were first estimated by PC Trask & Associates by synthesizing information from many literature sources. Scores were then refined through review and input by NOAA/NMFS's Northwest Fisheries Science Center, NMFS staff, Lower Columbia River Estuary Partnership staff, and Lower Columbia Fish Recovery Board staff. Additional review and input will occur from June to October 2006 to help refine and improve the estimates prior to publication in December 2006.

Also in Table 4-1, the contribution of each threat to its associated limiting factor(s) is multiplied by the relative importance of that limiting factor to salmonids (the relative importance of limiting factors is taken from Table 3-2). This yields a threat index score, which expresses the relative priority of the threat in question. Lastly in the prioritization process, Table 4-2 organizes threats by their threat index score, in descending order.

The state of the science is such that the differentiation of threat priorities in Table 4-2 should be viewed as reasonable guidance rather than hard, quantitative data. For example, it is difficult to dispute the importance of flow regulation compared to ship ballast practices. However, given uncertainties about ecosystems and how they function, some lower ranking threats may have tremendous impacts to the estuary in the long run. Continuing the example of ship ballast practices, it is possible that the effects of exotic invertebrates introduced to the estuary through ship ballast practices will significantly degrade the overall health of the estuary ecosystem over time.

Summary

The limiting factors that ocean- and stream-type ESUs encounter in the estuary are a result of upstream and estuary threats. Threats are well-documented in primary and secondary literature sources, although the complexity of interactions at the ecosystem-scale has caused treatment of threats to be inconsistent. New research efforts in the estuary and plume, as in other estuaries around the Northwest, are providing insights into salmonid ecology. For example, a recent University of Washington graduate student gathered data about prey and foraging activities of fall chinook salmon in the estuary and found midge insect prey to be a dominant food source. This raises new concerns about the threat of dikes and filling to ocean-type ESUs that rely on vegetated wetlands for insect prey. In addition, the identification of density-dependent mortality in the Skagit River delta has raised the question of whether density dependence-related mortality is also occurring in the Columbia

River estuary. Continued research by NOAA/NMFS's Northwest Fisheries Science Center and monitoring programs like the Lower Columbia River Estuary Partnership contaminant flux model should help reduce uncertainty over time.

The prioritization of threats in Table 4-2 is consistent with contemporary literature sources. Additional review and input from the scientific community in 2006 should help clarify the linkages among threats and limiting factors their significance.

In Chapter 5, management actions are identified and evaluated for their ability to address threats that perpetuate limiting factors, and costs to implement actions are estimated.

TABLE 4-2
Prioritization of Threats to Ocean- and Stream-Type Salmonids

Threat	Threat Index*	Threat Priority
Flow regulation	15	HIGH
Dikes and filling	15	
Altered predator/prey relationships	12	
Urban and industrial practices	12	
Agricultural practices	12	
Impaired transport of coarse sediment	12	
Pilings and pile dike structures	12	
Reservoir-related temperature changes	10	
Riparian practices	10	
Climate cycles and global warming	10	
Water withdrawal	10	
Dredging	8	
Entrapment of fine sediment in reservoirs	8	
Ship wakes	6	
Reservoir phytoplankton production	6	
Over-water structures	4	
Ship ballast practices	3	LOW

* From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.